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THE EFFECT OF FATIGUE ON FIRST STANCE PHASE KINETICS DURING ACCELERATION SPRINT RUNNING IN PROFESSIONAL FOOTBALL PLAYERS

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ABSTRACT

The study examined the effect of a fatiguing protocol on first stance phase kinetics during acceleration sprint running in professional football players. Nineteen participants (Age: 26 ± 5 years; Height: 1.84 ± 0.08 m; Mass: 83.4 ± 8.9 kg) completed three x 30 m maximal acceleration sprints from a standing start before completing the Yo-Yo intermittent recovery test level 1. Three x 30 m maximal acceleration sprints were then repeated post-fatigue. Light gates recorded sprint times from 0-5 m, 0-10 m, 0-15 m and 0-30 m. Force platforms collected ground reaction force of the first stance phase of the sprint run. Differences between pre- and post-fatigue were observed in the sprint times over 0-15 m ($P = 0.015$; CI [0.007, 0.110]) and 0-30 m ($P = 0.004$; CI [0.056, 0.234]). Peak medial-lateral ground reaction force was lower ($P = 0.045$; CI [-0.146, -0.005]) post- than pre-fatigue. The ratio of force were significantly different between pre- and post-fatigue for the medial-lateral and anterior-posterior comparison ($P = 0.017$; CI [-0.063, -0.010]), and the medial-lateral and vertical comparison ($P = 0.012$; CI [-0.036, -0.007]). Football players altered their sprint mechanics to reduce medial-lateral loading and orient the force in an increased anteroposterior and vertical direction in order to maintain 0-10 m sprint performance. Practitioners should observe medial-lateral force contributions and improve sprint technical efficacy.

KEYWORDS: Biomechanics, Fatigue, Physiology, Kinetics, Performance

INTRODUCTION

Team sports such as football, hockey, and basketball require performers to execute a number of short sprints, interspersed with periods of rest or low intensity activity (MendezVillanueva, Hamer & Bishop, 2007; Andrzejewski, Chmura, Pluta, Strzelczyk, & Kasprzak, 2013). Intermittent high-intensity endurance and the ability to repeatedly sprint within relatively short time intervals are deemed relevant fitness prerequisites in competitive football players (Krustrup et al., 2006; Morin, Samozino, Edouard & Tomazin, 2011a). Football players perform approximately 1300 movements, with 200 of these being completed at high intensity (Bangsbo et al. 2006). The majority of sprint runs associated with professional football are performed over short distances (0–10 m) (Di Salvo et al., 2010), with 90% of these lasting less than five seconds (Andrzejewski, Chmura, Pluta, Strzelczyk, & Kasprzak, 2013). Subsequently, intermittent training and testing protocols have been proposed to improve football players' fitness and guide talent selection (Bravo et al., 2008; Impellizzeri et al., 2008).

In exercise physiology, fatigue has been defined as strength loss and is generally divided into central (i.e. above the neuromuscular junction) and peripheral (muscular) (Millet, 2011). Fatigue has been shown to impair sprinting mechanics (Pinniger, Steele, & Groeller, 2000), muscular strength (Greig 2008; Small et al., 2008), and joint stability (Nyland, Shapiro, Stine, Horn, & Ireland, 1994). Although measured for the vastus lateralis, about half of the individual muscle fibers of types I and II have been shown to be depleted or almost depleted for glycogen post football match (Krustrup et al., 2006). Therefore, such a depletion of glycogen in some fibers may not allow for a maximal effort in a single sprint.

Hamstring injuries are most prevalent during the final 15 minutes of football matchplay (Woods et al., 2004). The biceps femoris is the most commonly strained muscle of the hamstring complex in professional football players (Woods et al., 2004) and is highly activated, greater than the semitendinosus, during the stance phase of an acceleration sprint performance (Higashihara et al., 2018). It could be assumed that reduced sprinting mechanics, knee flexor muscular strength and knee joint stability could influence subsequent injury risk. Moreover, with reduced force production from the knee flexors, this may reduce the capacity to generate increased anteroposterior forces during the stance phase of sprinting (Morin et al., 2015). Furthermore, energy absorption by the hamstring at the knee during late swing was previously

suggested to be responsible for continuing acceleration at near maximal velocities (Nagahara et al., 2017), and eccentric knee flexion endurance capability for maintaining highspeed sprinting performance (Krustrup et al., 2006; Greig 2008). Nagahara et al., (2016) suggested that an actual football match reduced maximal velocity capabilities more than horizontal force production abilities at initial acceleration, however they did not directly measure force and their results still observed reduced acceleration sprint performance in sprint times over 0-10 m and 0-20 m sprint times. Therefore, given that forceful contraction of the hamstrings are a key determining factor of sprint performance and the potentially injurious effect of fatigue on the hamstring for football players, it is important to understand the effect of fatigue on sprint running mechanics in football players.

The majority of current research investigating the ground reaction force (GRF) of acceleration sprint running has highlighted the importance of maximising anteroposterior propulsive forces (Colyer, Nagahara, & Salo, 2018; Nagahara et al., 2018a; Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2018b; Rabita et al., 2015), with further studies suggesting an increased forward orientation of GRF (Morin et al., 2011b, 2012; Rabita et al., 2015). A recent examination of the first stance GRF of semi-professional football players by Wdowski and Gittoes (2019) highlighted that acceleration sprint running in football requires minimised mediolateral and increased anteroposterior loading in the stance phase. However, although there is a plethora of current literature examining the kinetics of sprint running, there is limited examination of the effect of fatigue on the kinetics of acceleration sprint running.

Previous literature has examined the effect of fatigue on sprint running mechanics in physical education students (Morin et al 2011a), physically active males (Girard et al., 2011) and sprint trained males (Edouard et al. 2018). Morin et al. (2011a) reported that a repeated sprint protocol on an instrumented treadmill induced both a significant decrease in the capability to produce total force and an even larger relative decrease in the anteroposterior force component, which other treadmill based studies have supported (Edouard et al. 2018). In an attempt to avoid potentially altered running gait between over-ground and treadmill sprint running (McKenna & Riches, 2007), the effect of fatigue on over-ground sprinting running kinetics has been examined (Girard et al., 2011). Girard et al. (2011) suggested, in their examination of a repeated sprint protocol in physically active males, that decreased magnitude of braking and push-off peaks of anterior–posterior GRF were present post-

fatigue. However, in the current body of literature there is an absence of investigation into the effects of fatigue in a sport-specific cohort during more valid over-ground sprint running. Football players have been previously observed to rely on medial-lateral GRF's to enhance acceleration sprint performance (Wdowski & Gittoes, 2019). Such an investigation could provide novel insights into the mechanics of sprint running performance in fatigued conditions for football players.

Therefore, the present study aims to examine the effect of a fatiguing protocol on first stance phase kinetics during acceleration sprint running in professional football players. We hypothesise that sprint performance and anteroposterior propulsive forces would decrease post-fatigue.

MATERIALS AND METHODS

Participants

Nineteen full-time professional football players (Age: 26 ± 5 years; Height: 1.84 ± 0.08 m; Mass: 83.4 ± 8.9 kg) performing in the National League at the fifth level of the English football pyramid participated in the study. Training in pre-season focuses on the rebuilding of fitness in players following the off-season (Jeong et al., 2011), which consisted of two weeks off at the end of April and then a self-directed programme that included speed, strength and endurance. Tests were performed at the first training session of pre-season. All players were experienced at performing 30-m sprint assessments, as well as the Yo-Yo Intermittent Recovery Test level One as part of the battery of tests performed by the team over the season. Written informed consent was obtained from all participants prior to testing. The study was approved by the institutions ethics committee and complied with the current ethical standards in sports and exercise research.

Procedures

The participants initiated a warm-up protocol, which consisted of five minutes cycling, ten minutes of dynamic stretches and jogging, three x countermovement jumps, one-three repetition maximum test using box squats and three x 30 m sprints with 60s rest in between. Following the warm-up, the participants commenced the 30 m sprint assessment.

Participants were randomised into assessment groups of three-four participants. Individual participants performed three x 30 m maximal sprint accelerations from a standing start with 60 s rest between each sprint. Participants were instructed to position themselves with enough distance to lean comfortably forward without breaking the beam of the initial light gate with the toes of their favoured foot on the start line and their other foot comfortably behind. Participants initiated the sprint run themselves and completed a 30 m sprint run, accelerating maximally through five sets of Smartspeed™ PRO light gates (Fusion Sport, Grabba International Pty Ltd, London) positioned at the start line, and at five, ten, 15, and 30 m away from the start. The light gates were set at a height level to the participant's hip.

After the initial three sprints, the participants undertook the fatigue protocol which consisted of the Yo-Yo intermittent recovery test level One (Yo-Yo IRI) (Krustrup et al., 2003). A previous study observed that the Yo-Yo IRI is a valid and reliable field test to assess intermittent endurance in football players (Bangsbo, 2008). Furthermore, it has been reported that a lower Yo-Yo IRI performance is related to impairment in football-skill (i.e., shortpassing ability) during experimental matches (Rampinini et al., 2008). The Yo-Yo IRI was performed in an indoor sports hall by the participants according to the procedures suggested by Krustrup et al. (2003). Two minutes following the conclusion of the Yo-Yo IRI, participants executed a further three x 30 m maximal acceleration sprint performances following the same protocol as the sprints pre-fatigue. Two minutes was selected as it was approximately the mean recovery time (83 ± 26 seconds) between very high-intensity running bouts in English FA Premier League football matches (Bradley et al., 2009).

Data Collection

The start line was positioned 0.5 m posteriorly from the start of two parallel 0.90×0.60 force platform (AMTI OR6 Series Force Plate, USA, 800 Hz), mounted underneath an athletics track surface, so that the first foot strike of the sprint run would contact near the centre of either force platform. Force signals were low-pass filtered (fourth-order Butterworth, 70 Hz cut-off frequency) prior to analysis. The fastest 30 m trial where there was a good foot contact on the force platform during the pre- and post-fatigue sprints were used for further analysis as previous research has suggested that choosing the fastest trial are likely to provide similar outcomes to the average (Al Haddad et al., 2015).

The instants of touchdown and take-off from the force platform were defined when the vertical GRF first rose above ten Newton (N) (touchdown) and declined below ten N

(take-off). This period from touchdown to take-off was then defined as the contact time. Vertical (Z), anteroposterior (Y) and medial-lateral (X) GRF data were then exported for the duration of the contact time for each participant and expressed in Newton's (N) and Newton's/body weight (BW). Peak propulsive and mean average of the GRF for each of the X, Y and Z axis during the whole stance were identified, as well as peak Y braking force. Total force (BW) was calculated as the total mean average force (BW) applied in the X, Y and Z directions. Net impulse for the X, Y and Z directions were determined as the area under the GRF-time curve. Mean ratio of GRF vectors for the ZY comparison were calculated using the procedures outlined by Morin et al. (2011b). Where ratio of forces was calculated as the mean ratio of Y GRF to the total GRF of Y and Z. Corresponding measures of ratio of GRF vectors were determined for the XY and XZ components (Wdowski & Gittoes, 2019; Morin et al., 2011b).

Statistical Analysis

Means and standard deviations for the kinetic and sprint time metrics were calculated for all participants. Levene's test was used to check the homogeneity of variance and the Shapiro–Wilk statistics was used to check for data normality. As data was not normally distributed non-parametric statistics were used. A related samples Wilcoxon Signed Rank Test was processed to investigate the effect of pre- and post-fatigue. The importance of the differences found between pre- and post-fatigue was assessed through the effect size and Cohen's d coefficient (Cohen, 1988), interpreted as follows: small difference: $0.15 \leq d < 0.4$, medium difference: $0.40 \leq d < 0.75$, large difference: $0.75 \leq d < 1.10$ and very large difference: $d \geq 1.10$. The significance level was set at $P < 0.05$.

RESULTS

INSERT FIGURE 1 HERE

The participants achieved a distance of 1787.4 ± 448.6 m on the Yo-Yo IRI. The Group ensemble GRF pre- and post-fatigue in the X, Y and Z directions for the entire stance phase of the first step are presented in Figure 1 and the sprint time and GRF variables are displayed in Table 1. Significant medium and large increases post-fatigue were observed in the sprint times over the 0-15 m and 0-30 m distances. Peak X GRF had a significant medium decrease post-fatigue, the ratio of force had a significant medium decreases post-fatigue for the

medial-lateral and anterior-posterior comparison, and the medial-lateral and vertical comparison. Net impulse X was observed to have a significant medium decrease post fatigue and the ratios of force that involved the X GRF, had significant medium decreases postfatigue. The peak Y braking force had a significant medium positive increase post-fatigue when compared to pre-fatigue levels. Although there were medium effects observed between pre- and post-fatigue in the peak Z GRF and mean X GRF, these were not found to be significantly different.

INSERT TABLE 1 HERE

DISCUSSION

There is currently an absence of investigation into the effects of fatigue on GRF during overground sprint running in a sport specific cohort. Therefore, the current study aimed to examine the effect of a fatiguing protocol on first stance phase kinetics during acceleration sprint running in professional football players.

It was hypothesised that the fatiguing protocol would have a negative effect on acceleration sprint performance. The participants achieved a Yo-Yo IR1 distance covered of 1787.4 ± 448.6 m, which is similar to an observation (1760 ± 59 m) in a previous study with professional football players at the start of pre-season (Krustrup et al., 2003). Our results indicate that undertaking the Yo-Yo IR1 reduces acceleration sprint running performance over 0-15 m and 0-30 m but not 0-10 m or 0-5 m. The finding of the current study are in agreement with other repeated sprint running fatiguing protocols that previously highlighted a reduced sprint running performance over 0-5 m and 0-40 m (Jimenez-Reyes et al., 2019), and 5-10 m and 30-35 m (Girard et al., 2011). Previous literature has suggested that fatigue induced by a typical football match did not alter the maximal force component of sprinting, but altered the maximal velocity component (Nagahara et al., 2016). The reduced sprint performance over the final 20 m of the acceleration sprint run could be attributed to depleted glycogen stores (Krustrup et al., 2006), reduced muscle activation (Mendez-Villanueva et al., 2008) or alterations in neuromuscular activation of the contracting musculature (Billaut et al., 2007). Therefore, changes in GRF mechanics may be present towards the latter part of an acceleration sprint run over 30 m. We can suggest adding an endurance element in strengthening for the lower limbs, mainly for the knee flexors and hip extensor muscles since they are involved in sprint acceleration performance. Performing Nordic hamstring eccentric strengthening exercises during the cool-down (CD) or warm-up has been shown to significantly reduce the negative influence of fatigue

on eccentric hamstring strength (Small, McNaughton, Greig, & Lovell, 2009). Future research needs to examine whether the adaptation in GRF mechanics in football players as a result of fatigue is present during the late acceleration phase.

The current study observed no significant difference in performance post-fatigue over the first 0-5 m and 0-10 m. We had originally hypothesised that there would be a reduced anteroposterior (Y) propulsive forces post-fatigue. However, we observed that Y mean and peak forces were not significantly different post-fatigue. Previous research has argued that a decrease in performance post-fatigue could be caused by a fatigue-induced decrease in the total amount of force produced by the athletes onto the ground, or in the ability to orient the force in the anteroposterior direction, or both (Edouard et al., 2018). The findings of the current study suggest that an adaptation in the application of the force in the anteroposterior (Y) and maintenance of vertical force application (Z), combined with a reduced peak mediolateral (X) forces and impulse, enable performance to be maintained in the initial strides of a fatigued acceleration sprint run. These are novel findings, previous literature has not examined the medial-lateral force contribution post-fatigue, and only recently has literature highlighted the potential importance of medial-lateral force contribution for acceleration sprint running in football players (Wdowski & Gittoes, 2019). Given that the reduced mediolateral force contributions are important to acceleration sprint performance (Wdowski & Gittoes, 2019) and performance maintenance post fatigue in football players, improving sprint technical efficacy by perhaps constricting out of sagittal-plane motion during fatigued conditions, and specific strength training exercises for muscles implicated in sprint running (Morin et al., 2017; van den Tillaar et al., 2017) are warranted. Furthermore, when examining sprint running in football players practitioners should not ignore medial-lateral elements of force contribution.

Another element that could explain the maintenance of sprint acceleration performance over the initial 0-5 m and 0-10 m post-fatigue were the significantly reduced peak anteroposterior (Y) braking forces. Although football players who can accelerate faster have been suggested to initially apply force upon ground contact more vertically in order to reduce any anteroposterior braking forces, braking forces have not been explicitly correlated with acceleration sprint performance in football players (Wdowski & Gittoes, 2019). Previous investigation into the effects of fatigue on GRF, not in football players but physically active males, did not find any adaptation in peak anteroposterior (Y) braking forces but they did find reduced vertical stiffness and leg stiffness (Girard et al., 2011). A stiffer system could allow for more efficient elastic energy contribution, potentially enhancing force production during

the concentric push-off phase (Farley and Gonzalez, 1996). Although speculating, the reduced peak anteroposterior (Y) braking force could be as a result of reduced leg stiffness at foot contact. Future analysis into the late swing phase of the lead leg prior to touchdown in fatigue conditions may help elucidate whether it is a reduced vertical stiffness and leg stiffness or the kinematics and kinetics of the hip extension, which has been suggested to reduce braking forces (Bezodis et al., 2014), that results in the reduced anteroposterior (Y) braking force.

In football acceleration sprint runs, compensatory strategies could be an adaptation to maintain performance. While speculative, it could also be interpreted as a protective adaptation to limit hamstring muscles constraints and risk of damage (Edouard et al., 2018). Edouard et al (2018) has hypothesised that muscles playing a more important role in the second part of the acceleration in a non-fatigued condition (i.e., hamstring muscles) (Morin et al., 2015) do not equally assume this role in a fatigued condition. As a result of the weaker state of the hamstring muscles/knee flexors with fatigue, the hamstring muscles might be further exposed to injury risk, especially when high levels of force, velocity and power production are needed to produce sprint acceleration runs (Edouard et al., 2018). Therefore, hip extensors may compensate for the altered hamstring muscle function, which results in the adaptation in force interaction with the ground observed in the current study. Future research modelling the lower-limbs musculature contribution is required in over ground acceleration sprint running to ascertain the potential compensatory strategies of muscle in fatigued conditions.

It should be recognised that kinetic analysis in professional football players is more challenging than in adult samples and the value of the current study and future examinations lie in their comprehensive mechanical analysis undertaken and the unique value of this in informing effecting training and testing programmes. The main limitation of the study was that we investigated the first stance of a 30 m acceleration sprint run so were unable to comment on the effect of fatigue on GRF in the late acceleration phase. Future research needs to examine whether the adaptation in GRF mechanics in football players as a result of fatigue is present during the late acceleration phase. A further limitation is that alpha inflation as a result of multiple comparisons was not controlled for. The significant differences in kinetics under fatigue may inform practice to guide coaches to consider sprint technical efficacy in a

fatigued state to improve performance and reduce injury. However, further research is advocated to see how an intervention can improve performance in a fatigued state.

Conclusion

The current study aimed to examine the effect of a football specific fatiguing protocol on first stance phase kinetics during acceleration sprint running in professional football players. Football players were observed to alter their sprint mechanics to reduce medial-lateral loading and orient the force in an increased anteroposterior and vertical direction in order to maintain 0-10 m acceleration sprint performance. Their sprint performance was reduced post-fatigue in the final 20 m of a 30 m sprint run. Medial-lateral force contributions are important to acceleration sprint performance maintenance post fatigue in football players and as a consequence, practitioners should not ignore this element of force contribution and focus on improving sprint technical efficacy, joint stiffness and muscular strength to mitigate the influence of fatigue.

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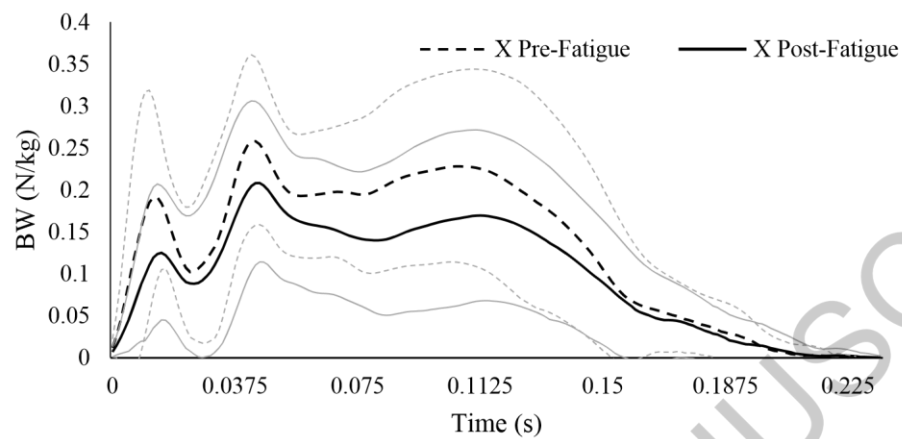
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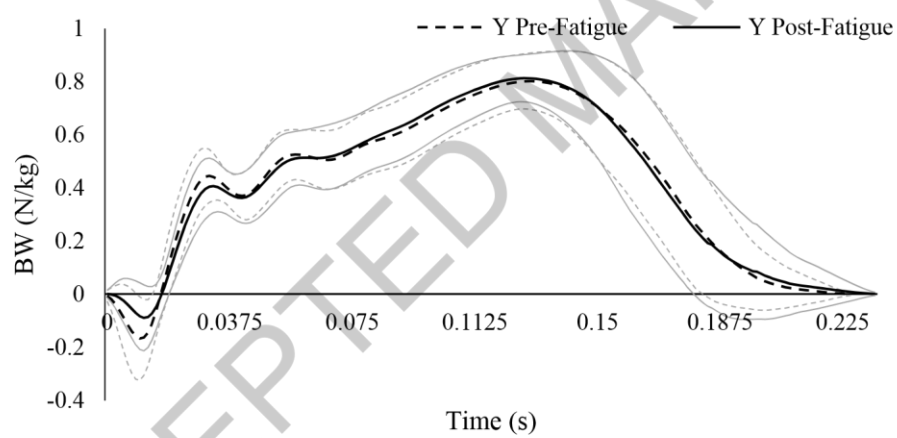
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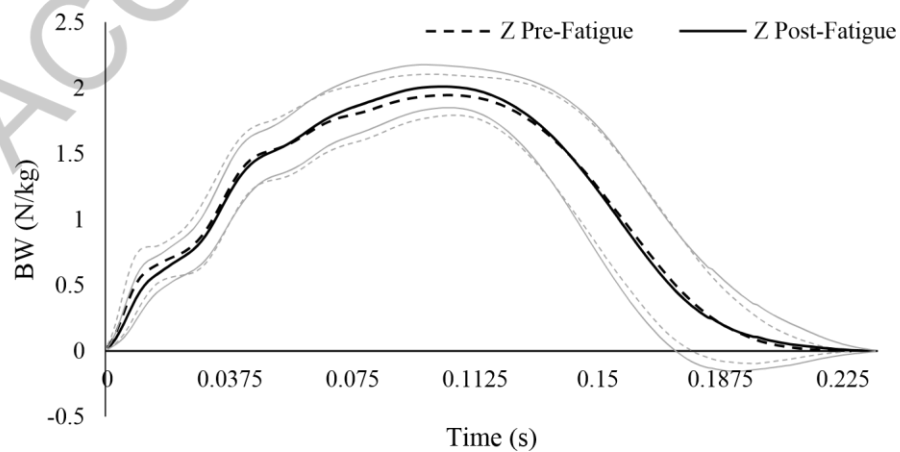
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a)



b)



c)

Figure 1. Group ensemble GRF pre- and post-fatigue in the X (a), Y (b) and Z (c) directions. Grey lines indicate the \pm SD of the pre and post-fatigue conditions.

Pre-Fatigue	Post-Fatigue	P- Value	Cohen's d	95% CI for Cohen's d	Mean Difference	95% CI for Mean Difference
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Table 1. Sprint time and GRF variables pre- and post-fatigue.

					Lower	Upper		Lower	Upper
0-5 m Sprint Time (s)	1.10±0.06	1.12±0.05	P = 0.264	0.27 Small Increase	-0.190	0.727	0.020	-0.015	0.055
0-10 m Sprint Time (s)	1.82±0.07	1.85±0.06	P = 0.305	0.24 Small Increase	-0.219	0.694	0.022	-0.022	0.065
0-15 m Sprint Time (s)	2.48±0.09	2.54±0.08	P = 0.015*	0.55 Medium Increase	0.060	1.027	0.058	0.007	0.110
0-30 m Sprint Time (s)	4.29±0.14	4.44±0.16	P = 0.004*	0.79 Large Increase	0.262	1.296	0.145	0.056	0.234
Peak Y Braking GRF (BW)	-0.18±0.15	-0.11±0.11	P = 0.041*	0.48 Medium Increase	-0.005	0.946	0.075	0.000	0.150
Peak X GRF (BW)	0.31±0.13	0.24±0.10	P = 0.045*	-0.52 Medium Decrease	-0.992	-0.032	-0.076	-0.146	-0.005
Peak Y GRF (BW)	0.85±0.07	0.86±0.07	P = 0.162	0.25 Small Increase	-0.212	0.702	0.014	-0.013	0.040
Peak Z GRF (BW)	1.99±0.14	2.06±0.16	P = 0.219	0.46 Medium Increase	-0.023	0.923	0.066	-0.004	0.135
Mean X GRF (BW)	0.15±0.05	0.12±0.06	P = 0.091	-0.51 Medium Decrease	-0.987	-0.028	-0.030	-0.058	-0.002
Mean Y GRF (BW)	0.49±0.04	0.49±0.04	P = 0.861	0.12 Small Increase	-0.336	0.566	0.004	-0.012	0.019
Mean Z GRF (BW)	1.27±0.10	1.28±0.09	P = 0.825	0.07 Small Increase	-0.382	0.519	0.006	-0.034	0.046
Total Force (BW)	1.91±0.16	1.89±0.11	P = 0.421	-0.20 Small Decrease	-0.648	0.260	-0.026	-0.089	0.037
Net Impulse X (BW.s)	0.029±0.012	0.023±0.013	P = 0.038*	-0.61 Medium Decrease	-1.094	-0.112	-0.007	-0.012	-0.001
Net Impulse Y (BW.s)	0.095±0.007	0.094±0.007	P = 0.480	0.06 Small Increase	-0.394	0.506	0.000	-0.003	0.004
Net Impulse Z (BW.s)	0.244±0.018	0.244±0.024	P = 0.760	0.01 Small Increase	-0.444	0.455	0.000	-0.010	0.010
Contact Time (s)	0.20±0.02	0.19±0.02	P = 0.354	-0.14 Small Decrease	-0.586	0.318	-0.002	-0.010	0.005
Ratio of Force (ZY)	0.30±0.02	0.30±0.03	P = 0.866	-0.11 Small Decrease	-0.557	0.345	-0.002	-0.012	0.007
Ratio of Force (XY)	0.25±0.07	0.22±0.06	P = 0.017*	-0.66 Medium Decrease	-1.145	-0.151	-0.036	-0.063	-0.010
Ratio of Force (XZ)	0.12±0.03	0.10±0.03	P = 0.012*	-0.73 Medium Decrease	-1.232	-0.215	-0.022	-0.036	-0.007

*Significant difference pre- and post-fatigue